A CONTRIBUTION TO THE FLOTATION OF SANTA CATARINA COALS

Dr. Eckart Hoffmann*

1. Introduction

Flotation is the usual cleaning process for fine coals - 0.6 mm. Increasing importance comes up to the flotation in Santa Catarina, in particular if the coal will be comminuted to a higher degree, corresponding to its liberation point. The flotation is able to be selective in those size ranges in which all other classical cleaning processes fail.

The works to be presented here aim to investigate the floatability of the Santa Catarina coals as a function of the raw material characteristics and the operation conditions.

2. Flotation in Santa Catarina

The preparation plants in Santa Catarina usually dispose of a flotation. The underflow of the CPL dewatering screen is thickened, in some plants processed on tables and, or in cyclones for additional pyrite and ash reduction and then passed on to flotation.

Although the fraction - 0.6 mm constitutes only a small portion in the Barro Branco run-of-mine coal, averaging 6.1%, special significance comes up to this coal due to its raw material characteristics. The FSI of the clean coal - 1.40 kg/dm³ of the fraction 0.6 - 0.074 mm is between 7 1/2 and 9. The clean coal of the fraction 1.2 - 0.6 mm, which partly gets into the flotation feed, has a similarly high FSI, i.e. 8. The FSI values of the density fractions 1.40 - 1.50 kg/dm³ are already lower because of the ash contents (FSI = 2). These figures are valid for the Siderópolis coal (1), but should be representative for the Santa Catarina fines. The percentage of fines in the plant feed usually amounts up to 10%.

The flotation results of the Siderópolis plant can be regarded as representative for Santa Catarina (Table 1). Major problems occur with the coal losses during desliming and above all with the domination of the sulfur content in the product.

Some results of earlier investigations by the author, working with CPL, are summarized in Figure 1 (upper curve). The curve runs very steeply from a yield of approximately 30%. That means, from this point the broad band of intercalated material begins to float. Consequently, investigations were carried out thereafter with careful comminution of the middlings, i.e. the residue after separation of low-in-ash coal and high-in-ash tailings. At first glance, however, the results were not very promising. It causes some difficulties to liberate the middlings with

*Engenheiro - Cooperação Técnica Brasil/Alemanha (GTZ/DNPM/CETEM)
reasonable technical investment. Additional investigations with ultrafine CPL - 0.044 mm lead to the results shown in Figure 1 (lower curve). The results of this multi-cleaner flotation are not yet of practical value. They only demonstrate that an excellent concentrate can be produced if the coal is extensively liberated.

By the way, working with this coal, the same results were obtained at competitive investigations between flotation and spherical agglomeration.

3. Test material

The investigations were executed with flotation feed of the Mina A of the Carbonífera Próspera. The coal has an ash content of 39.7 % (d.b.) and a sulfur content of 1.62 % (d.b.). The size-ash-sulfur distribution is shown in Table 2 with the ash content increasing with decreasing grain size which is considered to be normal. The sulfur content shows more or less the same tendency. In the fraction - 0.044 mm, roughly 24 % of the total ash and 21 % of the total sulfur are enriched.

For the determination of the density-ash-sulfur distribution a sink and float analysis was done, using a centrifuge for the fraction - 0.2 mm. The results of the flotation can be compared directly with the density separation, since both depend in their yield on the degree of intercalation. Figure 2 shows the washability curves as ash content vs. yield for the samples + 0.2 mm and - 0.2 mm and for the combined flotation feed. It is remarkable that practically no clean coal is present in the fine sample - 0.2 mm. The clean coal got lost during desliming and it can be assumed that these losses contain high-grade coking coal.

4. Test conditions

The test conditions were set in such a manner that an area as wide as possible was covered. Variables were

- reagent (collector) addition
- rotation and aeration, respectively
- solid content
- pH
- size distribution.

These parameters, besides the retention time, influence the coal flotation at a given raw material.

4.1. Flotation arrangement

The investigations were carried out, using a 4.5 l Denver flotation machine and all tests were run in rougher-cleaner arrangement. During the pre-investigations, different flotation circuits for coals of poor floatability were tested, resulting in the confirmation, that processing the Santa Catarina coals, sophisticated circuits do not lead to such significant qualitative and quantitative improvements, so that high technical expense would be compensated.

4.2. Flotation reagents

Selecting the flotation reagents, preference was given first to traditional and moreover national products. Usual
flotation oils (fother-collectors), such as Carbonol, Montanol and MIBC, will be researched in the next step.

Pine oil was used as frother in the range of 130 g/t, with 80 % of the oil added in the rougher and 20 % in the cleaner. During extensive pre-tests it was established that this quantity is appropriate for the lab scale flotation of the Santa Catarina coal, but the quantity is not necessarily the optimum for technical operations.

As collector a mixture of kerosene and diesel oil in the proportion 1,5:1 was applied. The ratio of the two components was due to dosage reasons. The collector was added in a pre-emulgated form from 0 to 2000 g/t, the dominant part always in the rougher. During the pre-tests there was no clear indication which of the two collectors is the more suitable one for the Santa Catarina coal, so that both were used. The pre-tests allowed only the presumption that kerosene could have a slightly better influence on the selectivity and diesel on the yield.

4.3. Solid content
The tests were run with solid contents of 100 and 200 g/l of water. These contents represent the range used in technical operation.

4.4. Rotation and aeration
The rotation and aeration, respectively, are of utmost influence on the coal flotation performance. The rotation was 1200 and 1800 min⁻¹, corresponding to a cell aeration of 3,8 and 14,0 1/min and 14,2 and 41,2 cm³/min x cm², thus conformed with 16,5 to 33,0 cm³/min x cm², used by Kubitzka and Lemke in a semi-technical scale (2).

4.5. pH
It is unknown that the pH can influence the coal flotation. Certainly the influence is by far not so important as with the flotation of some metal ores. Usually the flotation is carried out at the given pH. Generally spoken, the ash contents increase and the yields decrease in the high basic range.

The local pH in the Santa Catarina coal mining area is between 4 and 5. Most of the tests were run according to this pH, using sulfuric acid as modifying agent. Since the works aimed at the reduction of ash as well as tentatively at the reduction of sulfur, some parallel tests were executed at pH 11. Besides a low solid content and avoidance of reagent surplus, a pH above 10, regulated by slaked lime, is named above all as a favourable environment for the flotation of high-in-pyrite coals.

4.6. Size distribution
The majority of the tests were performed with the sample as received. In Santa Catarina desliming of the flotation feed is applied. Therefore, some tests were carried out processing deslimed material. (The sample was already deslimed once prior to sampling.) The lab scale desliming was done by wet screening. At the 0,044 mm cut 15 % with 60 % ash and at the 0,1 mm cut 24 % with over 50 % ash
were removed. Additionally, tests were run with separate flotation of the fractions +0.2 and -0.2 mm. This cut point was chosen because the separation can be easily obtained in technical operation, for instance by the KHD microscreen or by the Derrick screen.

4.7. Flotation time

The investigation of the flotation time was not subject of this work. The flotation time was 2.5 min in the rougher and 2 min in the cleaner. It was set in such a manner that high-in-ash tailings could be produced in order to minimize coal losses. Usually the flotation followed very quickly, especially with higher reagent addition, but was distinctly slower at lower reagent addition and processing the fines -0.2 mm.

5. Test results and evaluation

Altogether, 14 test series were performed. To identify the test conditions in the figures, abbreviations were used, for example 9/1200/100/5/+44, meaning series 9, rotation 1200 min, solid content 100 g/l, pH 5, deslimed at 0.044 mm. Figure 3 shows exemplarily for 2/1200/100/11 ash content of the concentrate, ash content of the tailings and yield as a function of the collector addition for both the rougher and cleaner. The curves exhibit the tendency to be observed nearly always that with growing addition of the collector the ash contents of both products and the yield increase more or less quickly and then take a constant course or decrease.

The Figures 4 to 8 show in direct comparison the flotation results of the rougher and cleaner under the different test conditions in the form ash content vs. yield. It is obvious that the flotation of the Santa Catarina coal performs better at
- lower solid content (Figure 4)
- lower rotation and aeration, respectively, (Figure 5)
- acid range (Figure 6).

Figure 7 shows the flotation results with normal and deslimed feed. Not only in the rougher, but also in the cleaner, the result with deslimed feed is better until a certain recovery. Beyond this recovery, however, the flotation with undeslimed feed is more favourable. The reason is based on the coal losses in the ultrafine slimes. The absence gets perceptible with increasing yield. In Figure 8 the results of the separate flotation are given. Here the deficient selectivity of the flotation of the fines -0.2 mm is obvious.

These lab scale investigations, of course, are not sufficient to answer the question whether the flotation feed in Santa Catarina is to be deslimed or not. But they indicate that the desliming is not absolutely of that benefit which is expected. If the aim is to produce a particularly high-grade concentrate, the flotation feed should be deslimed. If a high yield is aimed at, the natural fines should be processed.
The flotation behaviour of the pyrite was very indifferent and reflected only the experience, that the sulfur content decreases with the ash content, as shown in Figure 9. By this, the flotation behaviour of coals is confirmed on the whole, and the floatability of the Santa Catarina coal must be called normal. This statement certainly does not cover the products. Qualities, as achievable with other coals, can hardly be obtained with this typical Gondwana coal.

6. Assessment on the efficiency of the Santa Catarina flotation
The knowledge of the density-ash distribution allows an assessment on the efficiency of the flotation. Figure 10 shows in form ash content vs. yield the results of the flotation and the sink and float analysis of the + 0,2 mm fraction. Above a yield of approximately 50 % a very good conformity can be noted between the theoretical and the flotation performance. That means, that in this range the flotation takes its optimum course according to the density structure. At lower yields the ash content in the product is higher, since with deficient presence of collector not all clean coal particles float, especially not the coarse ones, but on the other hand coal particles with higher ash contents float too early which do not belong into the corresponding density fraction. The same circumstances occur with the flotation of the fines - 0,2 mm (Figure 11). In this case, extremely fine rock particles carried with arrive additionally at the froth product, leading to an over-proportional increase of the ash content. Figure 12 illustrates the facts for the total flotation feed.

With inclusion of the Siderópolis flotation results, 52 % yield and 17 % ash, it is possible to assume a function in Figure 12 for the yield range of 40 to 60 % which is of operational interest. The position of this function to the ideal function allows only the conclusion that with the given coal an essential improvement of the flotation with regard to ash content and yield cannot be expected. By the way, a rule of thumb can be derived from the results obtained for the Santa Catarina fines, that by means of one-stage flotation the ash content of the concentrate can be reduced to half of the initial ash content. Only by reflotation of the first concentrate the ash content can be adjusted to the one of a coking coal.

7. Outlook
All future investigations should aim to improve the national coking coal basis. This can be effected under quantitative and qualitative aspects. Quantitative means that coals which up to now are used for another purpose will be ground and cleaned by flotation. Qualitative means that a coking coal higher in value is produced, since "the good coking properties of the Santa Catarina coals should better be used to bind non-binding or poorly coking cheap
blend coal than to be wasted by binding non-carboniferous substances" (3).
Whatever the preparation plant of the nearer future will be in Santa Catarina, there should be no doubt concerning the ponderosity of the flotation. A coal technologist of the German Bergbauforschung expressed it this way: "Após ter conhecimento dos carvões brasileiros, sou da opinião de que a única possibilidade de aumentar o rendimento do esquema de beneficiamento dos carvões brasileiros, seria a utilização do processo de flotação com espuma" (4).

8. Bibliography


9. Tables and figures

<table>
<thead>
<tr>
<th>Product</th>
<th>Yield %</th>
<th>Ash %</th>
<th>S %</th>
</tr>
</thead>
<tbody>
<tr>
<td>underflow of the dewatering screen</td>
<td>100,00</td>
<td>50,0</td>
<td>3,10</td>
</tr>
<tr>
<td>Slimes</td>
<td>45,00</td>
<td>62,2</td>
<td>4,80</td>
</tr>
<tr>
<td>Flotation feed</td>
<td>55,00</td>
<td>40,0</td>
<td>1,70</td>
</tr>
<tr>
<td>Flotation tailings</td>
<td>26,50</td>
<td>64,7</td>
<td>1,00</td>
</tr>
<tr>
<td>Flotation concentrate</td>
<td>28,50</td>
<td>17,0</td>
<td>2,40</td>
</tr>
</tbody>
</table>

Table 1: Balance of the Siderópolis flotation plant

<table>
<thead>
<tr>
<th>Size mm</th>
<th>Yield %</th>
<th>Ash %</th>
<th>S %</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 1,2</td>
<td>0,20</td>
<td>33,8</td>
<td>1,57</td>
</tr>
<tr>
<td>1,2 - 0,6</td>
<td>15,20</td>
<td>24,2</td>
<td>1,22</td>
</tr>
<tr>
<td>0,6 - 0,42</td>
<td>25,90</td>
<td>29,9</td>
<td>1,24</td>
</tr>
<tr>
<td>0,42 - 0,3</td>
<td>12,00</td>
<td>31,9</td>
<td>1,35</td>
</tr>
<tr>
<td>0,3 - 0,21</td>
<td>11,50</td>
<td>38,4</td>
<td>1,27</td>
</tr>
<tr>
<td>0,21 - 0,15</td>
<td>11,40</td>
<td>39,1</td>
<td>1,58</td>
</tr>
<tr>
<td>0,15 - 0,1</td>
<td>6,90</td>
<td>41,7</td>
<td>2,05</td>
</tr>
<tr>
<td>0,1 - 0,074</td>
<td>6,20</td>
<td>42,9</td>
<td>2,55</td>
</tr>
<tr>
<td>0,074 - 0,044</td>
<td>5,50</td>
<td>47,8</td>
<td>3,07</td>
</tr>
<tr>
<td>- 0,044</td>
<td>15,30</td>
<td>60,4</td>
<td>2,31</td>
</tr>
</tbody>
</table>

Table 2: Size-ash-sulfur distribution of the Mina A flotation feed
Figure 1: Ash content vs. yield for flotation of CPL - 0.6 mm (above) and - 0.044 mm (below)

Figure 2: Ash content vs. yield, sink and float analysis of Mina A flotation feed
- 0.6 - 0.2 mm
- 0.2 mm
- 0.6 mm

Figure 3: Ash content of the concentrate and the tailings, as well as yield vs. collector addition for 2/1200/100/11
Figure 4:
Ash content vs. yield for different solid contents (roug her and cleaner)
--- 1/1200/100/5
--- 5/1200/200/5

Figure 5:
Ash content vs. yield for different rotations (roug her and cleaner)
--- 1/1200/100/5
--- 3/1800/100/5

Figure 6:
Ash content vs. yield for different p , (roug her and cleaner)
--- 1/1200/100/5
--- 3/1200/100/11

Figure 7:
Ash content vs. yield for different size distributions (roug her and cleaner)
--- 1/1200/100/5
--- 9/1200/100/5/44
--- 10/1200/100/5/+100
Figure 8:
Ash content vs. yield for different size distributions (rougner and cleaner)
- 13/1200/100/5/+200
- 14/1200/100/5/-200

Figure 10:
Ash content vs. yield, comparison between sink and float analysis and flotation
(rougner and cleaner) of the +0.2 mm material
- Sink and float
- 13/1200/100/5/+200

Figure 9:
Sulfur content vs. ash content for different flotation conditions
Figure 11:
Ash content vs. yield, comparison between sink and float analysis and flotation (rougher and cleaner) of the -0.2 mm material

Figure 12:
Ash content vs. yield, comparison between sink and float analysis and flotation (rougher and cleaner) of the Mina A flotation feed

<table>
<thead>
<tr>
<th>YIELD %</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASH CONC. %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2 mm material</td>
<td>28</td>
<td>24</td>
<td>20</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>Sink and float</td>
<td>24</td>
<td>20</td>
<td>16</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>14/1200/100/5/-200</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>YIELD %</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASH CONC. %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mina A flotation feed</td>
<td>24</td>
<td>20</td>
<td>16</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Sink and float</td>
<td>20</td>
<td>16</td>
<td>12</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>1/1200/100/5</td>
<td>16</td>
<td>12</td>
<td>8</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>1/1200/100/5/+44</td>
<td>12</td>
<td>8</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1/1200/100/5/+100</td>
<td>8</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>+ Sideropoli flotation</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>